Noninvasive Cardiovascular Monitoring

CPT Fletcher M Boulware Jr. MD

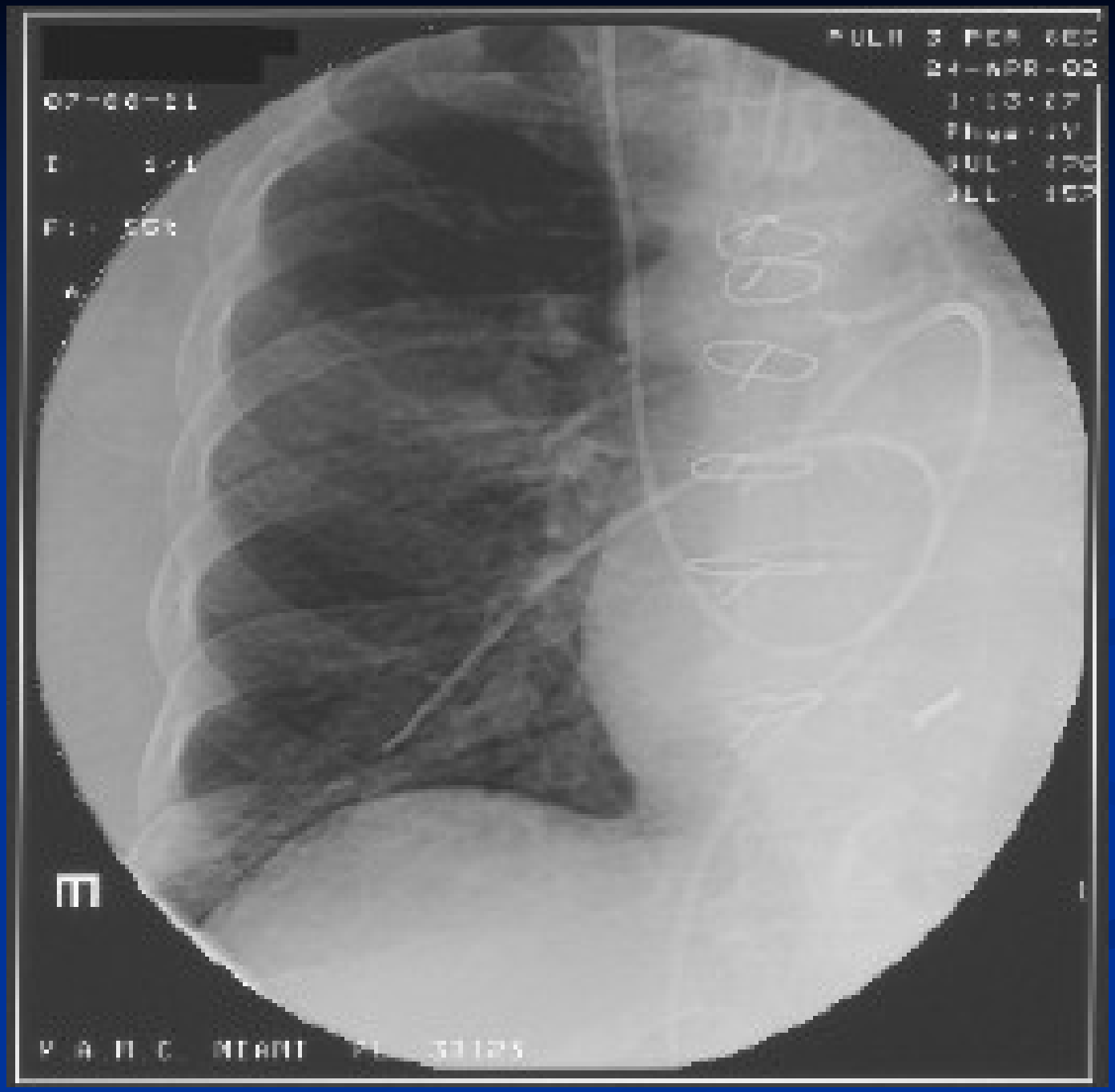
Grand Rounds Presentation

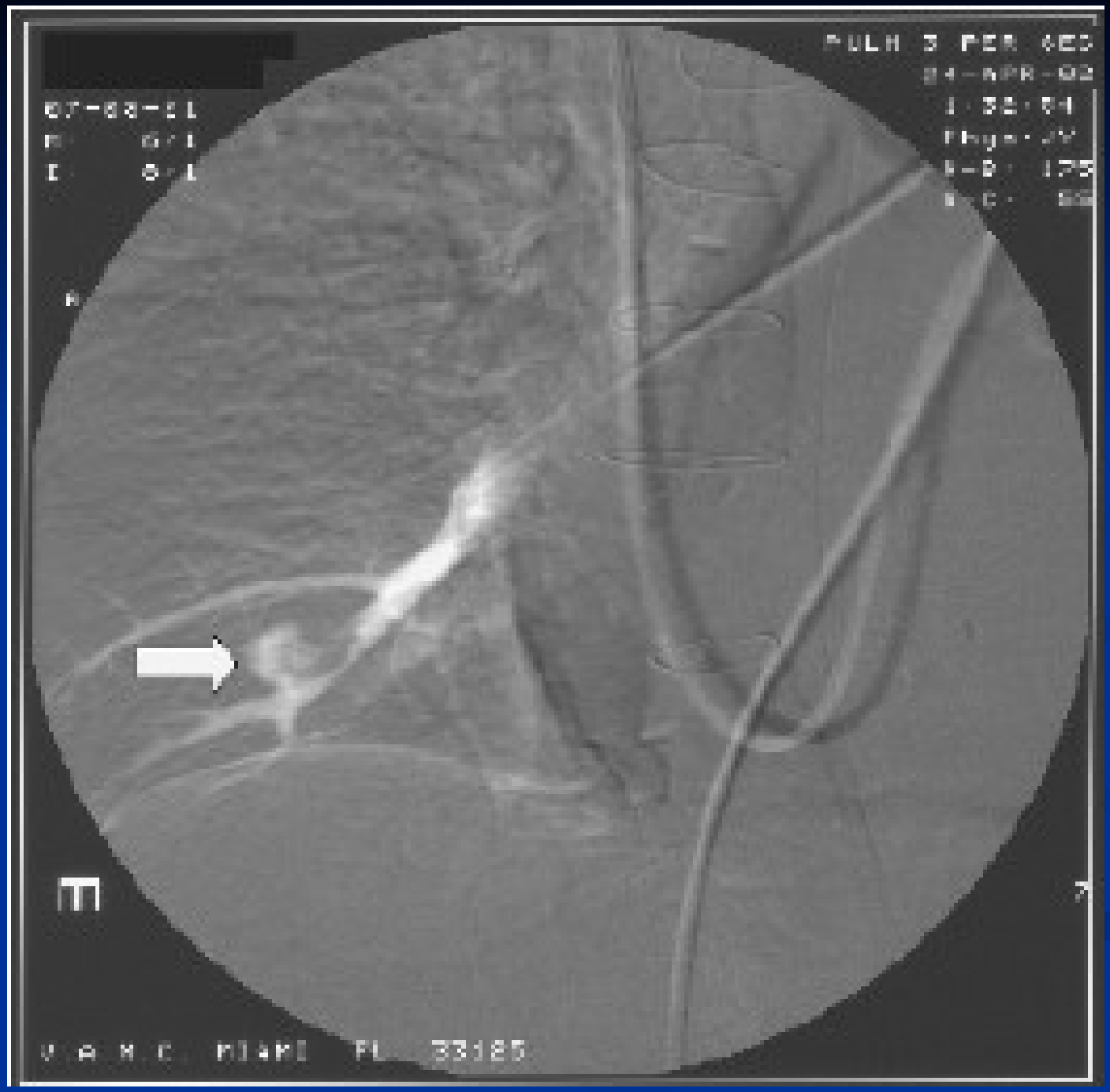
Case Presentation

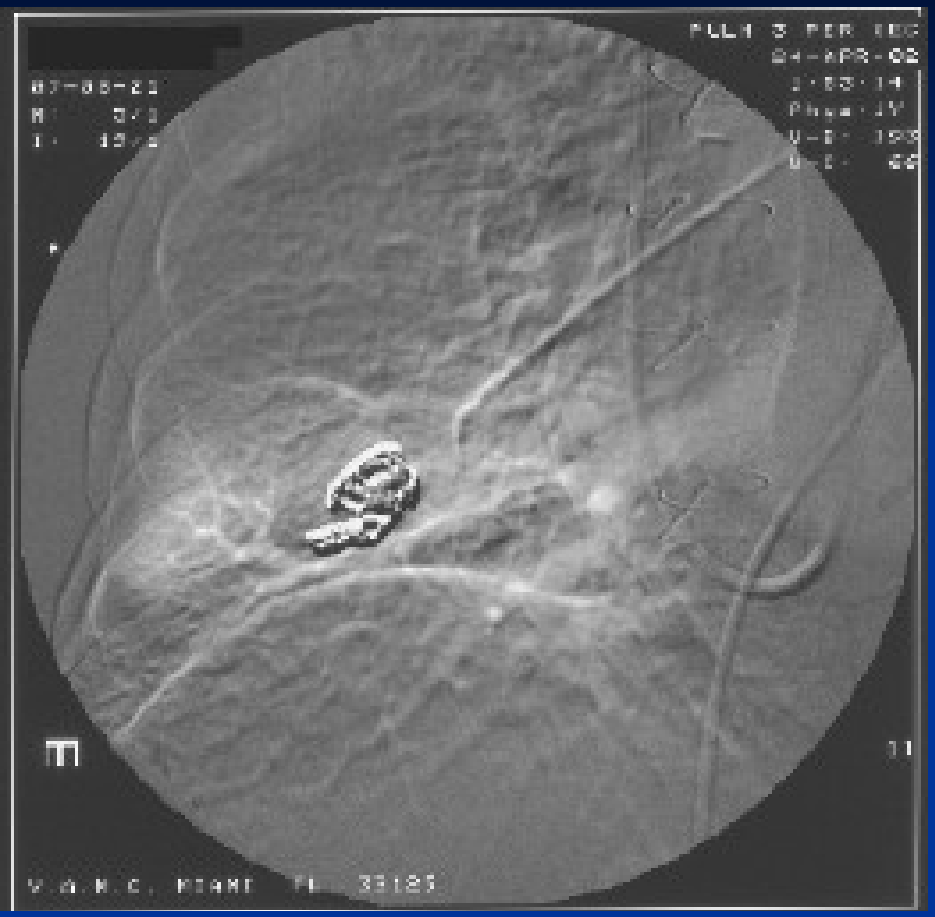
- 80 YOF with CAD and poorly controlled DM admitted to the ICU for sepsis from a left foot cellulitis
- She developed hypoxemia and worsening pulmonary infiltrates and was subsequently intubated
- Aggressive fluid resuscitation along with vasopressor therapy failed to produce adequate perfusion pressures

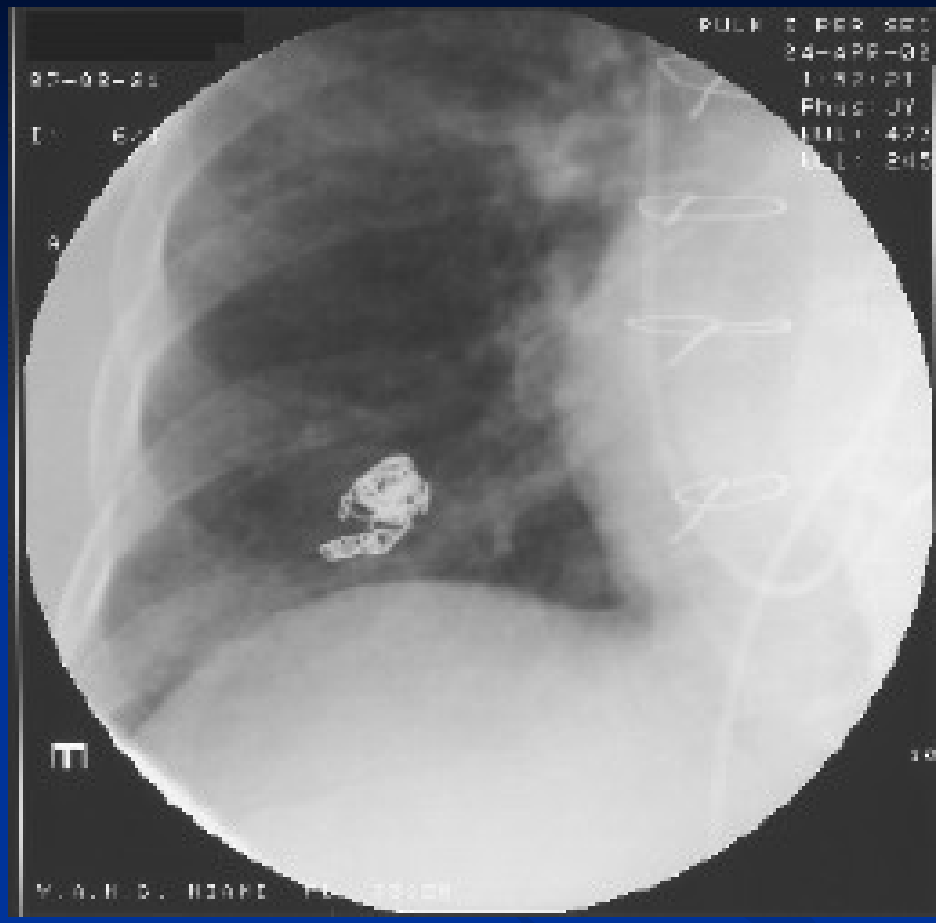
Case continued

- Decision made to place PAC to guide therapy
- PAC placed without complication, yet 15 minutes after balloon inflation massive hemoptysis noted from ET tube
- Portable CXR shows PAC tip into distal pulmonary artery









Noninvasive technology

- Procedures
- Anesthetic techniques / Drugs
- Imaging
- Monitoring

Noninvasive cardiovascular monitoring

- Continuous arterial blood pressure
- Central venous pressure / PAOP
- Cardiac output
- Novel measurements

ABP

- Techniques
  - Auscultation
  - Oscillometry
  - Tonometry

Indications for continuous ABP

- Large fluctuations in BP
- Non-pulsatile flow – CPB
- Frequent lab draws

Contraindications

- Need adequate perfusion
- Infection
- Hypocoaguable state
- Dialysis grafts

Noninvasive ABP

Medwave Vasotrac

Medwave Primo

Physics

$$\text{pressure} = \frac{\text{force}}{\text{area}}$$

Noninvasive ABP

- Contraindications
- Advantages
- Disadvantages

Accuracy – T-Line

- 25 patients undergoing GA
- Compared to invasive A-line in contralateral arm
- The mean ± sd bias (mm Hg)
  - Sys - 1.7 ± 7.0
  - Diastolic - 2.3 ± 6.9
  - Mean - 1.7 ± 5.3
- Range systolic 41 to 189

Gregory M. Janelle and Nikolaus Gravenstein **An Accuracy Evaluation of the T-Line® Tensymeter (Continuous Noninvasive Blood Pressure Management Device) versus Conventional Invasive Radial Artery Monitoring in Surgical Patients** Anesth. Analg. 2006 102: 484-490

More accuracy data

- Nearly 150,000 paired data points over more than 57 hours of monitoring were collected and analyzed
- Systolic Pressure - Mean Error - 1.0 – STD 7.2
- Diastolic Pressure – Mean Error – 0.8 STD 7.5
- Mean Pressure – Mean Error – 1.3 STD 6.2
- AAMI SP-10:2002 - Accuracy Specification of a mean error not exceeding ±5 mm Hg and a standard deviation not exceeding 8 mm Hg

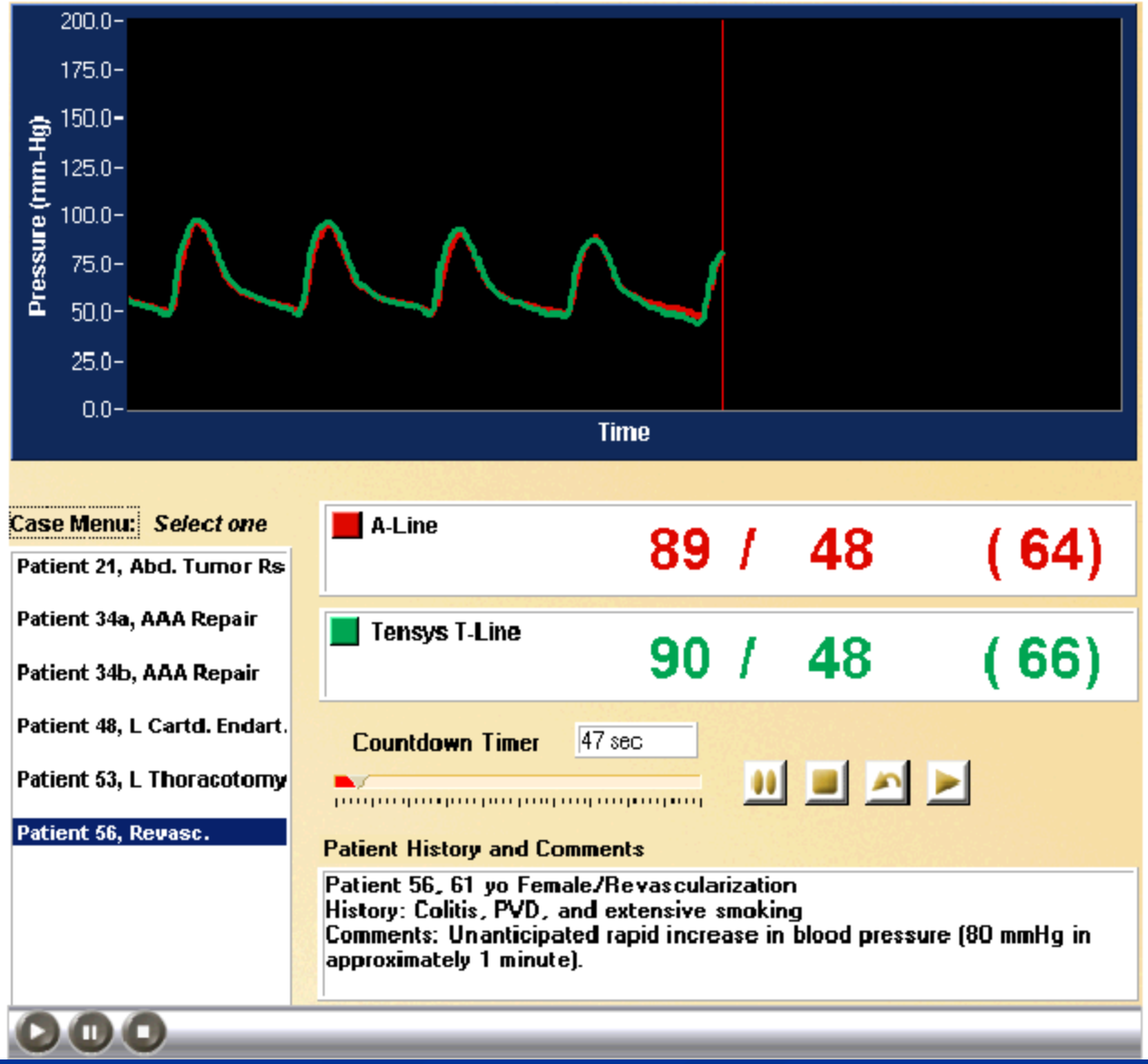
Vasotrac Accuracy

- 80 Patients for surgery or in ICU
- Vasotrac vs contralateral radial artery tonometer
- R values
  - Systolic=0.93
  - Diastolic=0.89
  - Mean=0.95
- Pulse Rate 0.95

A New Noninvasive Method to Measure Blood Pressure: Results of a Multicenter Trial.

Anesthesiology. 91(3):686, September 1999. Belani, Kumar M.D. *; Ozaki, Makoto M.D. +; Hynson, James M.D. ++; Hartmann, Thomas M.D. [S]; Reyford, Hugo M.D. [//]; Martino, Jean-Marc M.D. #; Poliac, Marius Ph.D. **; Miller, Ronald M.D. ++

61 YOF for Distal Bypass



Obesity T-line

- 9 Female patients
- BMI > 30
- Systolic 10-beat Average Error – Mean 1.6 STD 7.6
- Diastolic 10-beat Average Error – Mean 4.2 STD 8.1
- Mean 10-beat Average Error - Mean 3.3 STD 7.5

Evaluation of Safety and Accuracy of the T-Line® Tensymeter (Continuous Non-Invasive Blood Pressure Management Device) versus Conventional Invasive Radial Artery Tonometry in Clinically Obese Surgical Patients R. L. Marcus, S. Ahmad, R. Glassenberg, P. Fitzgerald; (Northwestern University Feinberg School of Medicine, Chicago, IL)

Vasotrac - Obesity

- 33 Patients for gastric banding or gastric bypass
- Vasotrac vs A-line vs NIBP Cuff
- VS A-line
  - Sys 0.86
  - Diastolic 0.85
  - Mean 0.89
- VS NIBP Cuff
  - Sys – 0.60
  - Dia – 0.59
  - Mean 0.34

Continual Non-Invasive Blood Pressure Monitoring with the VasotracTM -Experience in the Morbidly Obese Au*thors:* DS Beebe MD, I Ostanniy MD, V Komanduri MS, M Poliac PhD, KG Belani MBBS MSPu*blication/Journal:* ANESTHESIOLOGY, V89, No. 3A, September 1998

Summary noninvasive ABP

- Accurate
- Useful?
- Expensive
- When will we see

Cardiac Output

- CO = HR x SV
- Normal in 70kg is about 5L/min
- Flow = Pressure / Resistance
- CO = BP / SVR

Cardiac Output

- Stewart-Hamilton

$$\dot{Q} = \frac{I}{\int_0^{\infty} C_I \, dt} \qquad (1)$$

Indicators

- Dyes
- Radioactive tracers
- Thermodilution
- Lithium dilution

Thermodilution

$$\dot{Q} = \frac{(T_B - T_I) \cdot K}{\int_0^{\infty} \Delta T_B(t)\,dt} \qquad (2)$$

Errors

- Shunts
- Right sided valvular lesions
- Inadequate delivery of thermal indicator
- Central venous injection site within the catheter introducer sheath – malposition
- Warming of iced injectate
- Thermistor malfunction from fibrin or clot
- After cardiopulmonary bypass – pulmonary blood temperature change
- Rapid intravenous fluid administration
- Respiratory cycle influences

Fick

$$\dot{Q} = \frac{\dot{V}O_2}{(CaO_2 - C\bar{v}O_2) \cdot 10} \qquad (3)$$

$$S\bar{v}O_2 = SaO_2 - \frac{\dot{V}O_2}{\dot{Q} \cdot 1.36 \cdot Hgb} \qquad (4)$$

Indications

- To optimize fluid/pharmacologic management in patients with abnormal cardiac or vascular function to achieve normal or supernormal oxygen delivery to organs

Complications

- Pulmonary artery rupture
- Right heart block
- Cardiac puncture
- Dysrythmias
- Knotting
- Air embolus
- Infection / Sepsis

Less invasive cardiac output

- Doppler
- Partial inert gas rebreathing
- Intravascular pulse contour analysis
  - PiCO
  - PulseCO/LiDCO

Doppler

- Transtracheal
- Esophageal
- TEE

Partial inert gas rebreathing

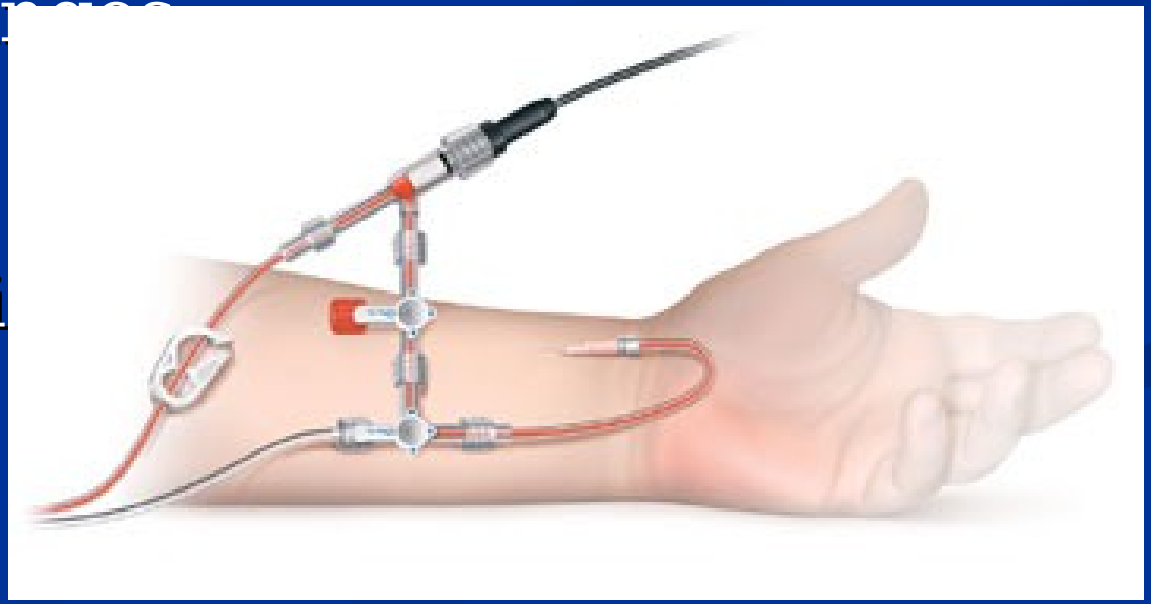
$$\dot{Q} = \frac{\dot{V}CO_2}{(C\bar{v}CO_2 - CaCO_2)} \qquad (14)$$

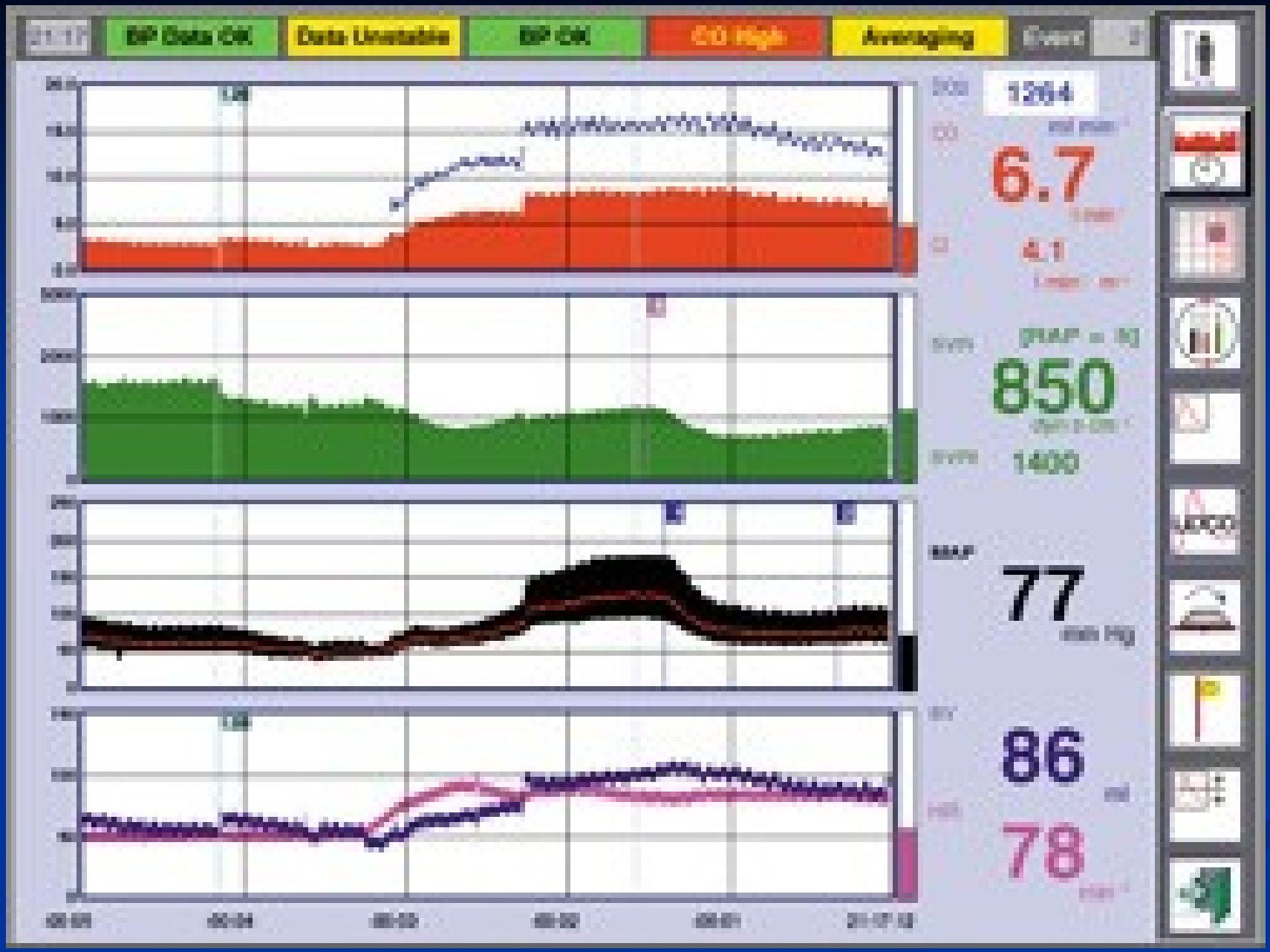
PiCO

- Uses arterial waveform analysis
- Requires transpulmonary dilution (central line to fem /axilllary catheter) for calibration

LiDCO / Pulse CO

- Uses existing arterial line
- Analysis pulse waveform to give a raw measurement of volume changes in the arterial system
- Lithium chlori calibration




BP Data OK
Data Unstable
BP OK
CO High
Averaging
1264
6.7
4.1
850
1400
77
86
78

Validation

- 19 cardiac surgery patients in ICU
- Pulse contour analysis vs pulmonary thermodilution
- Mean difference 0.31 +/- SD 1.25 L/min
- R = 0.88

J Cardiothorac Vasc Anesth. 2000 Apr;14(2):125-9 Beat-to-beat measurement of cardiac output by intravascular pulse contour analysis: a prospective criterion standard study in patients after cardiac surgery. Zollner C, Haller M, Weis M, Morstedt K, Lamm P, Kilger E, Goetz AE.

No good in Off-pump CABG

- 23 Patients for OPCABG
- PulseCO vs thermodilution during
  - Sternotomy – $r^2 = 0.49$
  - Mediastinal opening – $r^2 = 0.52$
  - End of surgery – $r^2 = 0.55$

Can J Anaesth. 2005 May;52(5):530-4 Cardiac output by PulseCO is not interchangeable with thermodilution in patients undergoing OPCAB. Yamashita K, Nishiyama T, Yokoyama T, Abe H, Manabe M

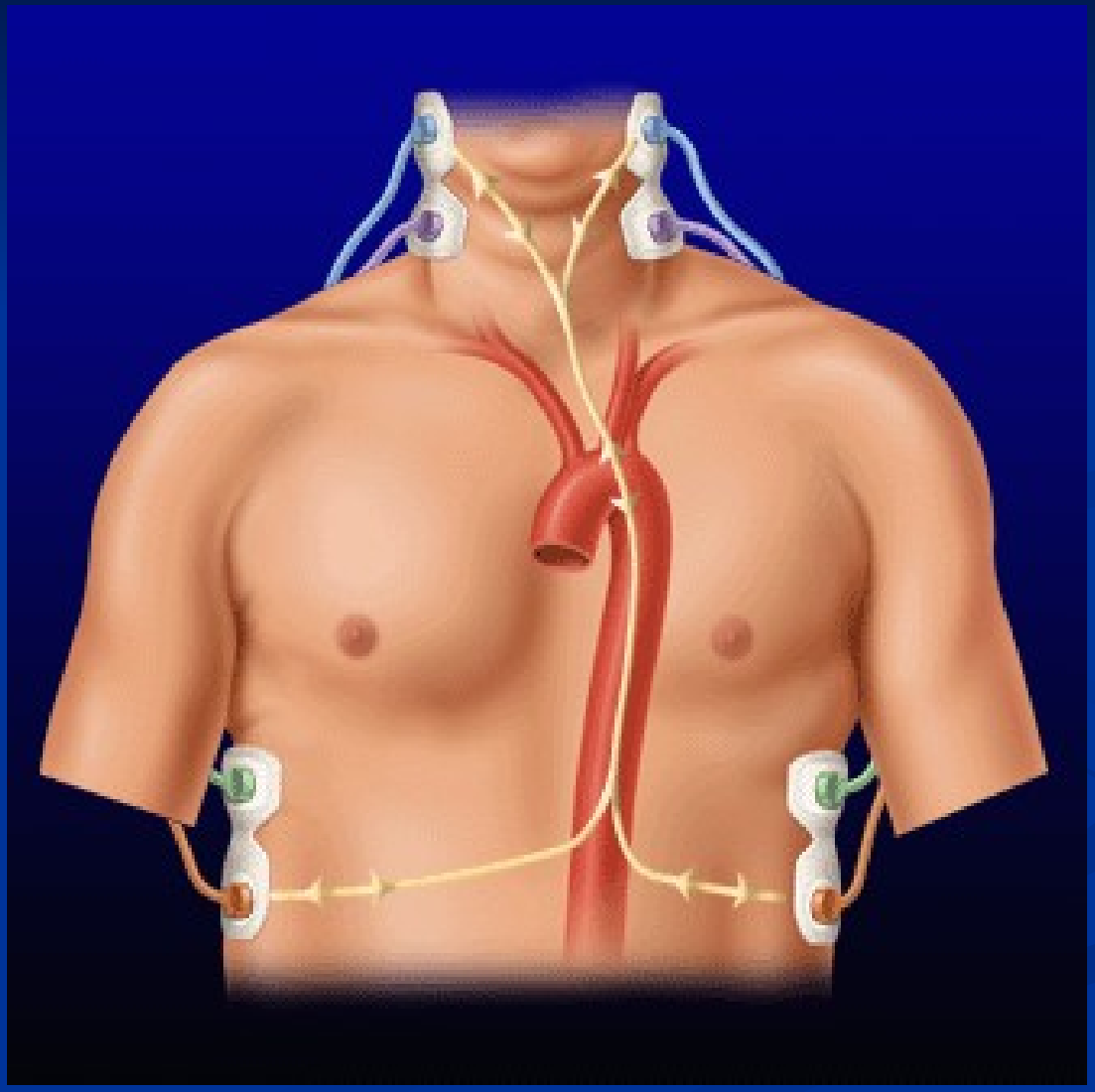
Disadvantages

- Must have functioning A-line
- Calibration required every eight hours
- Not accurate in all clinical scenarios

Noninvasive cardiac output

- Bioimpedance
- Flotrac

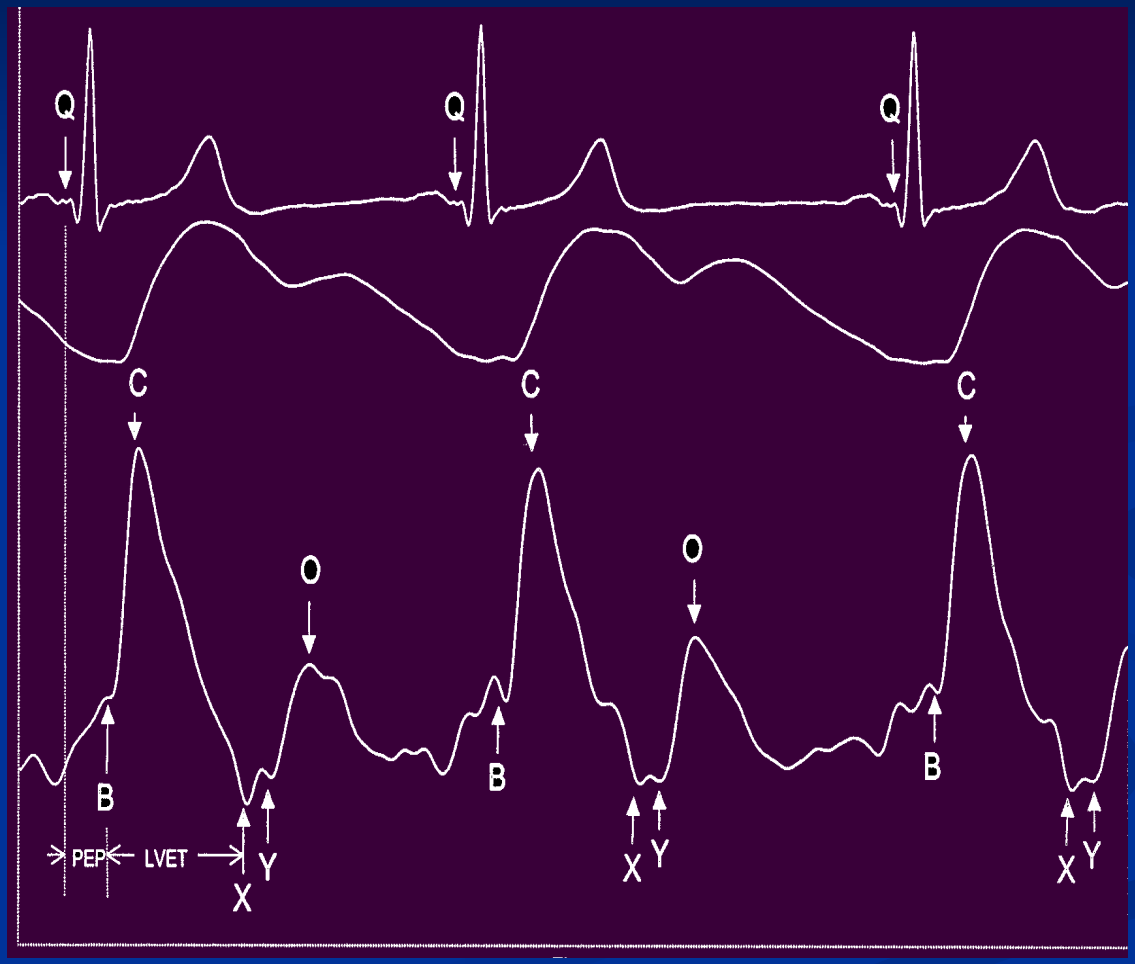
Bioimpedance (BioZ)

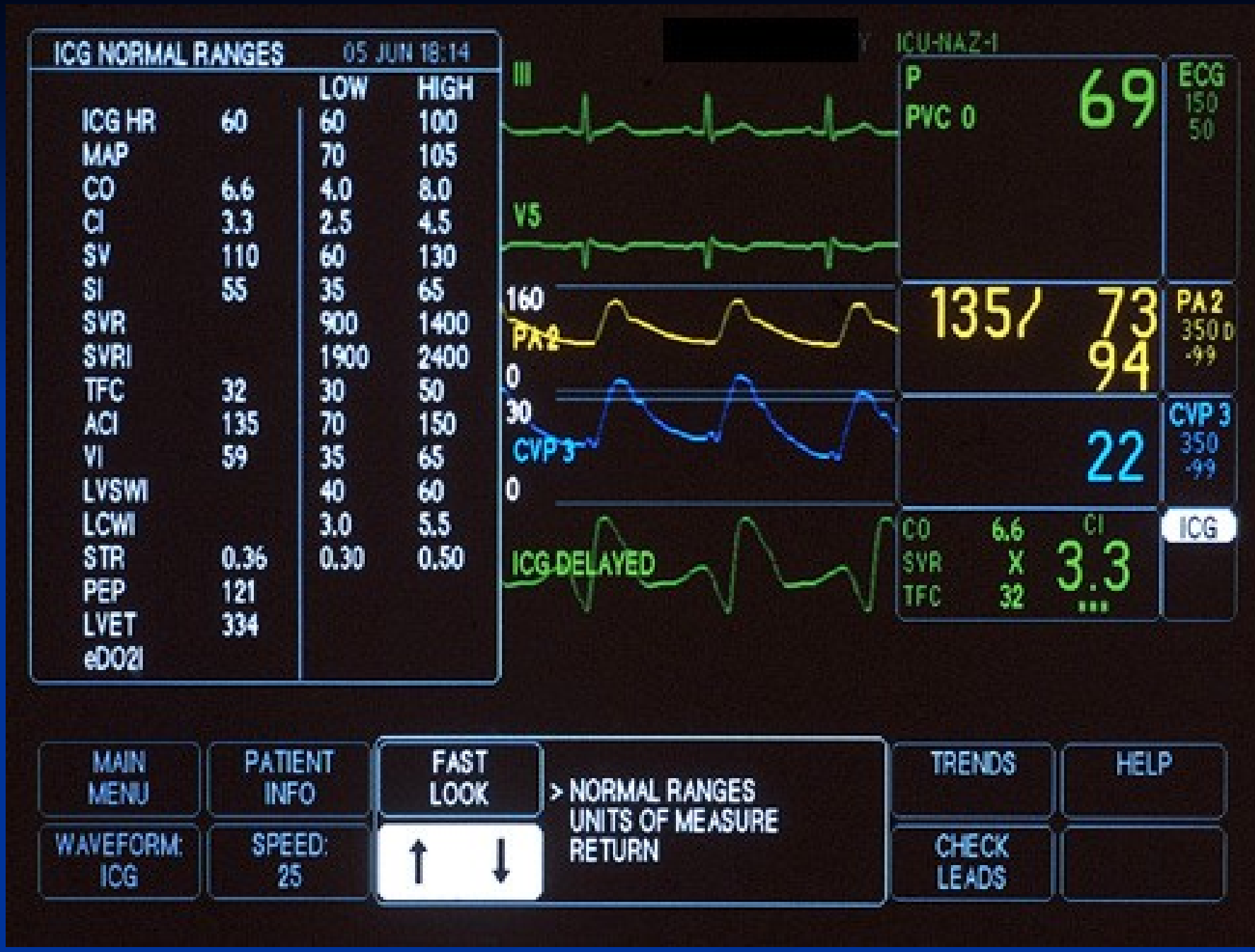


Bioimpedance

$$SV = \frac{\rho L^2}{Zo^2} \cdot VET \cdot \max \frac{dZ}{dt} \qquad (13)$$

ECG and BioZ waveforms




ICG NORMAL RANGES
05 JUN 18:14
LOW
HIGH
ICG HR 60 60 100
MAP 70 105
CO 6.6 4.0 8.0
CI 3.3 2.5 4.5
SV 110 60 130
SI 55 35 65
SVR 900 1400
SVRI 1900 2400
TFC 32 30 50
ACI 135 70 150
VI 59 35 65
LVSWI 40 60
LCWI 3.0 5.5
STR 0.36 0.30 0.50
PEP 121
LVET 334
eDO2I
ICU-NAZ-1
III
V5
160
PA2
0
30
CVP 3
0
ICG DELAYED
P
PVC 0
69
ECG
150
50
135/ 73
94
PA 2
350 D
-99
22
CVP 3
350
-99
CO 6.6
SVR X
TFC 32
CI
3.3
ICG
MAIN MENU
PATIENT INFO
FAST LOOK
> NORMAL RANGES
UNITS OF MEASURE
RETURN
TRENDS
HELP
WAVEFORM: ICG
SPEED: 25
CHECK LEADS

BioZ Accuracy

- BioZ vs PA Thermodilution after cardiac surgery
- 20 Post CPB patients
- Simultaneous measurements
- Correlation Coefficient of 0.99

J Cardiothorac Vasc Anesth. 2002 Feb;16(1):8-14. Equivalence of bioimpedance and thermodilution in measuring cardiac index after cardiac surgery. Sageman WS, Riffenburgh RH, Spiess BD Pulmonary Medicine, Monterey, CA , USA

BioZ Accuracy

- 53 Post CPB ICU patients
- 210 pairs of measurements
- BioZ vs TD - $R = 0.811$
- Variability in each technique 6.3% vs 24%

Impedance Cardiography: The Next Vital Sign Technology?*Chest*. 2003;123(6):2028-2033.**Authors:**Van De Water JM, Miller TW.

BioZ in CHF

- 33 Stable ICU patients with Dx of CHF
- 4 dropped due to inability to get reliable measurements

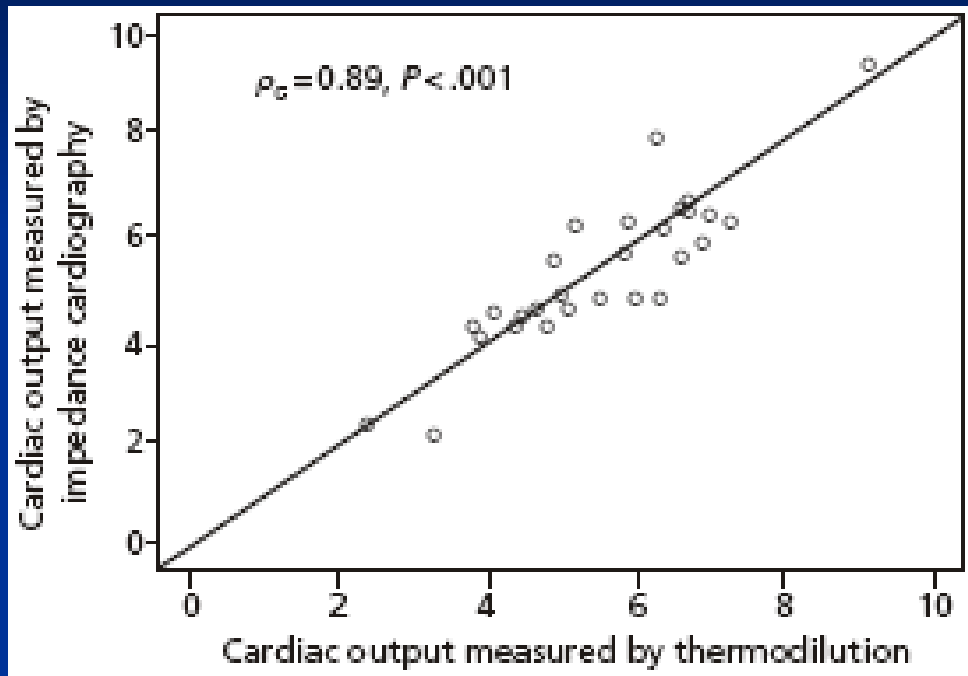


Figure 1 Concordance correlation plot for cardiac output. Diagonal line shows where data points would be if both techniques provided identical values.

Equivalence of Bioimpedance
and Thermodilution in Measuring Cardiac Output and Index in Patients with Advanced,

BioZ in pulmonary HTN

- 39 Patients referred for eval of PHTN
- Right heart cath
- BioZ vs TD vs Fick
- Correlation
  - BioZ vs TD – 0.80
  - BioZ vs Fick – 0.84

Comparison of Impedance Cardiography to Direct Fick and Thermodilution Cardiac Output Determination in Pulmonary Arterial Hypertension.Co*ngest Heart Fail*. 2004;10(2 suppl 2):7-10.Authors:Yung GL, Fedullo PF, Kinninger K, Johnson W, Channick RN.

Eliminate need for PAC

- 107 patients in coronary care unit
- 14 patients determined to need hemodynamic monitoring by treating physician
- Physicians given data from BioZ
- 10/14 patients determined not to need a PAC
- Physicians said the BioZ was helpful in all 10
- Physicians said that it improved outcome in 6/10 patients

Congest Heart Fail. 2004 Mar-Apr;10(2 Suppl 2):17-21 Evaluation of impedance cardiography as an alternative to pulmonary artery catheterization in critically ill patients. Silver MA, Cianci P, Brennan S, Longeran-Thomas H, Ahmad F.

Advantages

- Easy to initiate
- Limited clinical expertise needed
- Noninvasive
- Accurate
- Outpatient / Emergency
- Cost effective

Disadvantages

- Not accurate in all clinical scenarios
- New / Unfamiliar

Flotrac

- Connects to existing A-line
- No calibration method required

Validation

- 84 Surgical / ICU patients
- Already had PAC in place
- Flotrac vs thermodilution
- Grouped measurements - 562 data points
- Mean difference 0.19 SD 1.28 L/min had

Validation of Continuous Cardiac Output Measurement Using Arterial Pressure Waveforms William T. McGee et al Critical Care Supplement Mar 05

Disadvantages to less/noninvasive cardiac output

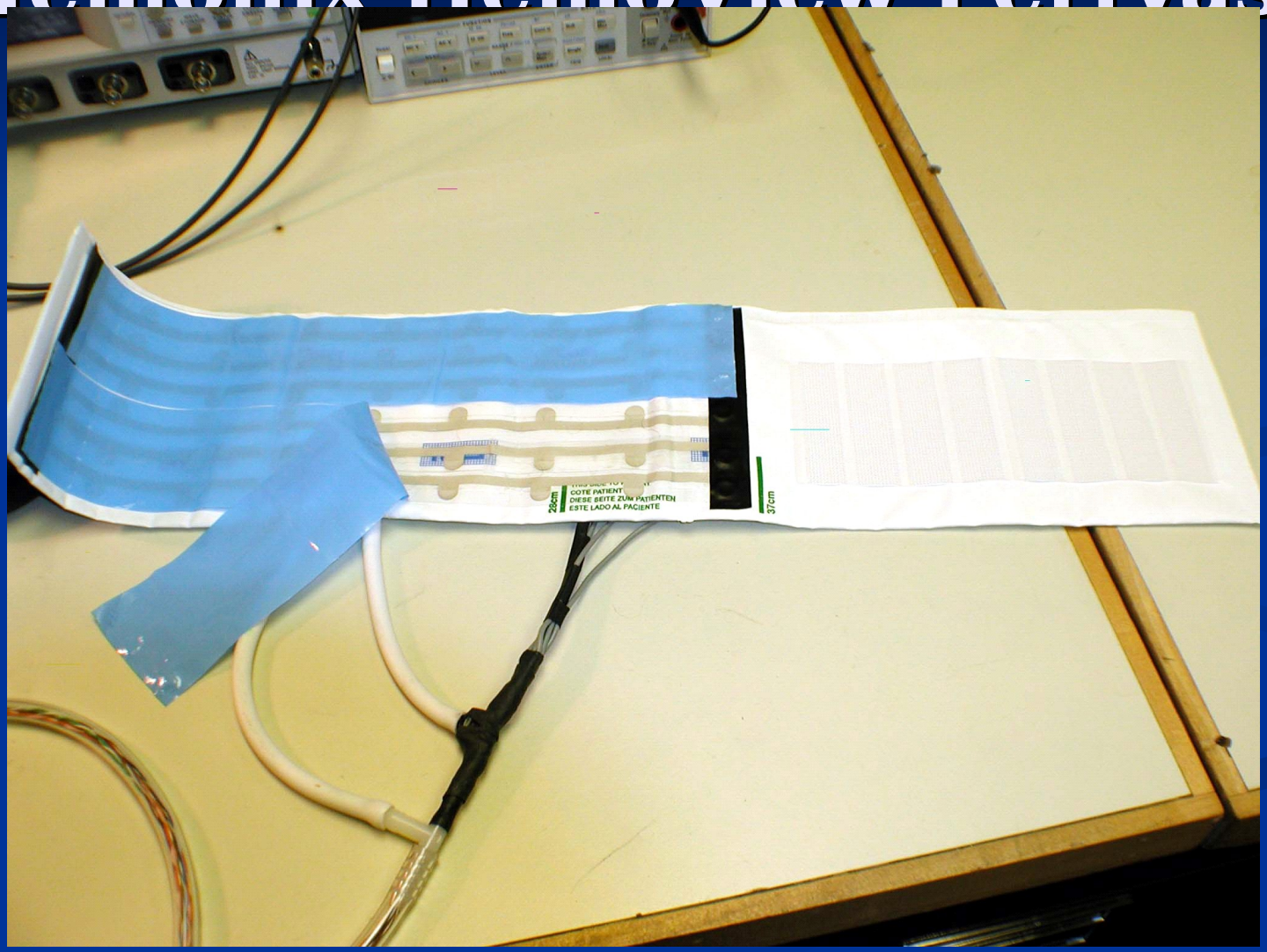
- PA pressures
- No PA occlusion pressure
- Mixed venous saturation

Summary noninvasive CO

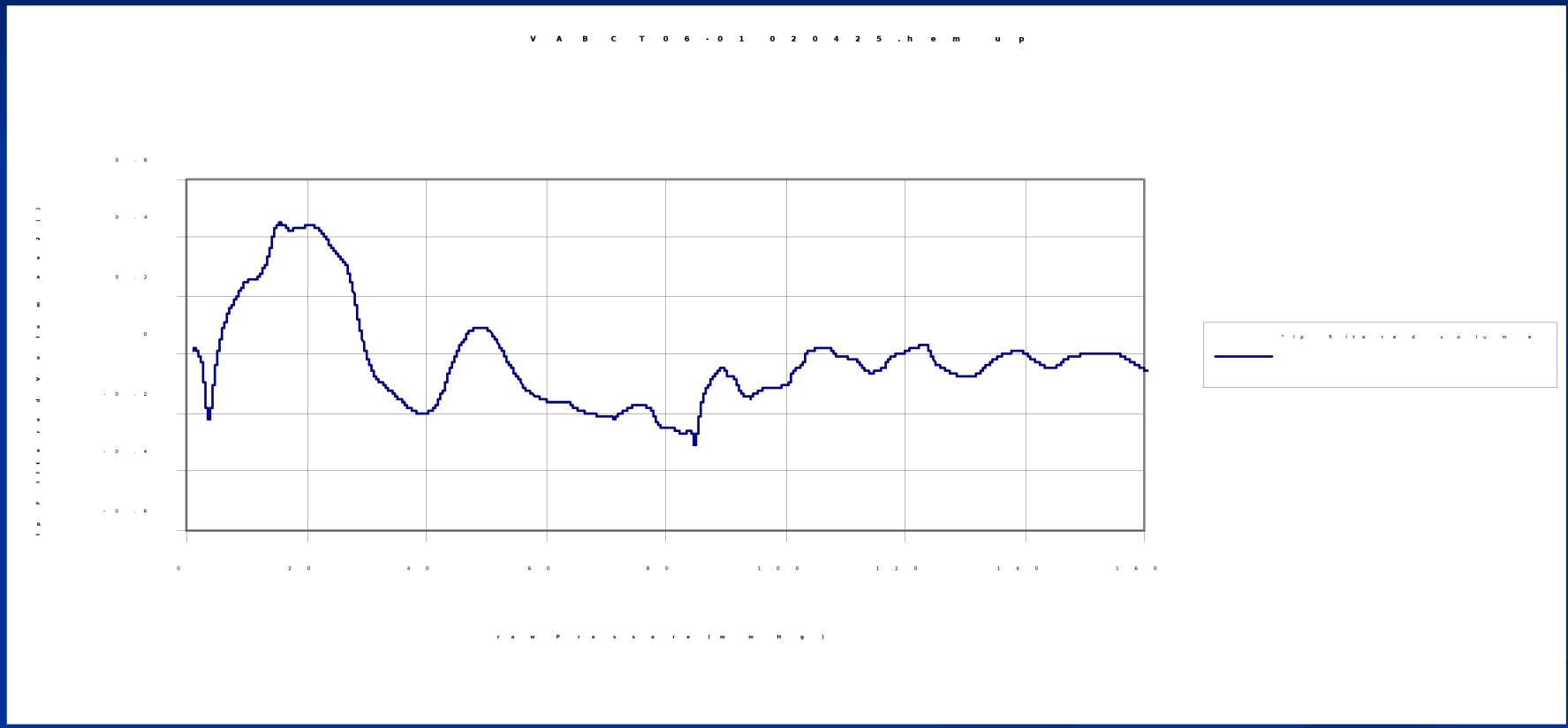
- Accuracy
- Utility
- Cost

Novel cardiovascular parameters

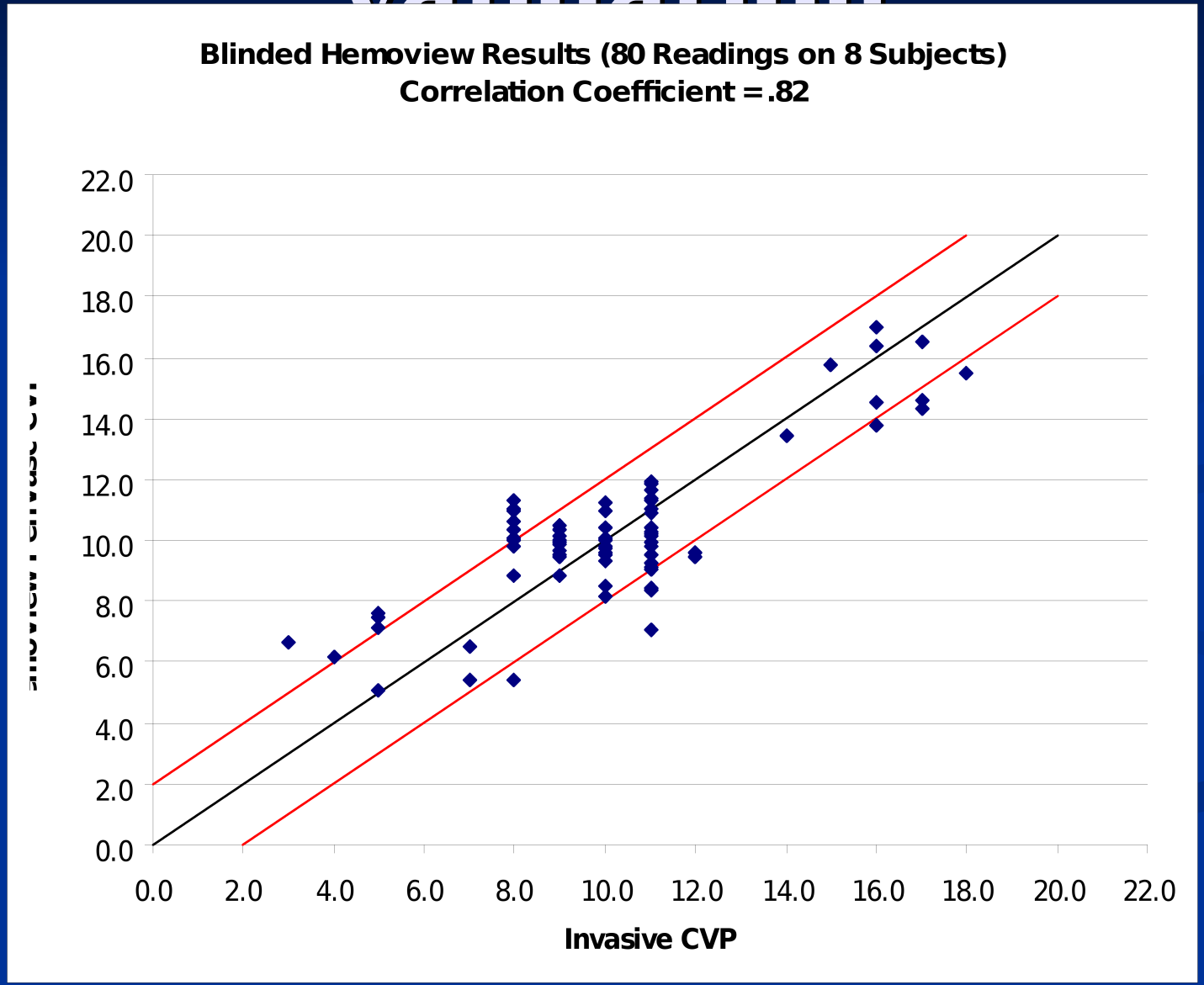
Hemonix HemoView PeriVasc



Non-invasive intermittent CVP



Non-invasive CVP validation



Intravascular volume

- Ratio of arterial blood to venous blood volume to total blood volume
- Ratio of intravascular blood volume to extravascular blood volume
- Ratio of intravascular blood volume to total body volume?!

Other measured parameters

- CO
- Continuous ABP – without any pressure applied
- Hematocrit
- $$$

And beyond

- Existing technology implemented
- Pharmacogenmoics
- TCI
- Nanomedicine – Respirocites

References

Fegler G: Measurement of cardiac output in anesthetized animals by a thermodilution method. Q J Exp Physiol 39:153–164, 1954.

Berger RL, Weisel RD, Vito L, et al: Cardiac output measurement by thermodilution during cardiac operations. Ann Thorac Surg 21:43–47, 1976.

Jansen JRC: The thermodilution method for the clinical assessment of cardiac output. Intensive Care Med 21:691–697, 1995.

Levett JM, Replogle RL: Thermodilution cardiac output: A critical analysis and review of the literature. J Surg Res 27:392–404, 1979.

Journal of Intensive Care Medicine, Vol. 19, No. 5, 291-296 (2004)
DOI: 10.1177/0885066604265255 Pulmonary Artery Rupture Induced by a Pulmonary Artery Catheter: A Case Report and Review of the Literature Alexandre R. Abreu, MD Michael A. Campos, MD Division of Pulmonary and Critical Care Medicine, Department of Medicine, University of Miami School of Medicine, Miami, Florida Bruce P. Krieger, MD

Nishikawa T, Dohi S: Errors in the measurement of cardiac output by thermodilution. Can J Anaesth 40:142–153, 1993.

Evaluation of Safety and Accuracy of the T-Line® Tensymeter (Continuous Non-Invasive Blood Pressure Management Device) versus Conventional Invasive Radial Artery Tonometry in Clinically Obese Surgical Patients R. L. Marcus, S. Ahmad, R. Glassenberg, P. Fitzgerald; (Northwestern University Feinberg School of Medicine, Chicago, IL) *Presented at the International Anesthesia Research Society 80th Clinical & Scientific Congress. San Francisco, CA March 24-28, 2006.* Presentation Number: S-154

References continued

An Accuracy Evaluation of the T-Line® Tensymeter (Continuous Noninvasive Blood Pressure Management Device) versus Conventional Invasive Radial Artery Monitoring in Surgical Patients
Gregory M. Janelle, M.D., and Nikolaus Gravenstein, M.D. (Department of Anesthesiology, University of Florida College of Medicine, Gainesville, FL)

Reliability of Hypotension Detection with Noninvasive Radial Artery Beat-to-Beat versus Upper Arm Cuff BP Monitoring
Ron Dueck, M.D. (Anesthesiology, University of California, San Diego and VA San Diego Healthcare System, San Diego, CA), Leslie C. Jameson, M.D. (Anesthesiology, University of Colorado Health Science Center, School of Medicine, Denver, CO) *Presented at the Society for Technology in Anesthesia 2006 Annual Meeting. San Diego, CA January 17-21.*

The New TL-150 Tensymeter® Continuous Noninvasive BP (CNBP) Versus Direct Radial Artery Measurement of Labile Blood Pressure
Ron Dueck, M.D. (Anesthesiology, University of California, San Diego and VA San Diego Healthcare System, San Diego, CA)

Comparison of NIBP with T-Line® Tensymeter® (Continuous NIBP Device) for BP Concordance in ASA II-IV Patients Leslie C. Jameson, M.D., Colleen K. Dingmann, R.N., Ph.D. (Anesthesiology, University of Colorado Health Science Center, School of Medicine, Denver, CO)

Temporal Performance of the T-Line® Tensymeter® (Continuous Non-Invasive Blood Pressure Management Device) versus Conventional Invasive Radial Artery Tonometry in Surgical Patients. G. M. Janelle, S. Gallant, A. Butler, M. Wilson, N. Gravenstein (University of Florida, Gainesville, FL; Tensys® Medical Inc., San Diego, CA)

References continued

Non-Invasive, Beat-to-Beat Radial Arterial Pressure Monitor (T-Line® TL-100) Provides Blood Pressure Equivalent to Standard Intra-Arterial Catheter Leslie C. Jameson, M.D. (Anesthesiology, University of Colorado, School of Medicine, Denver, CO)

Comparison of the T-Line® Tensymeter ® (Continuous Non-Invasive Blood Pressure Management Device) with Conventional Invasive Radial Artery Tonometry in Surgical Patients Gregory M. Janelle, M.D., Anthony Butler, Mark Wilson, Nikolaus Gravenstein, M.D. (Anesthesiology, University of Florida, Gainesville, FL)

Continuous Blood Pressure Monitoring and Patient Safety David B. Swedlow, M.D. (formerly Senior Vice President of Medical Affairs and Technology, Nellcor Puritan Bennett, Inc.) *Data on file, Tensys Medical, Inc*

A Comparison of the T-Line® Tensymeter® Device vs Direct Radial Arterial Pressure during Major Surgery Thomas Bellehumeur, M.D., James Ramsay, M.D. (Department of Anesthesiology, Emory University School of Medicine, Atlanta, GA)

Accuracy of the T-Line® Tensymeter ® (Continuous Non-Invasive Blood Pressure Management Device) Versus Conventional Invasive Radial Artery Tonometry in Surgical Cases with Induced Hypotension Peter Szmuk, M.D., Evan Pivalizza, M.D., Ralf Gebhard, M.D., Didier Sciard, M.D., Robert D. Warters, M.D. (Anesthesiology, University of Texas Medical School at Houston and Outcome Research Institute, Houston, TX)

PeriVasc: A Noninvasive Vascular Microscope Patent # 6,749,567 other patents pending *Charles L. Davis Hemonix, Inc.*

J Cardiothorac Vasc Anesth. 2002 Feb;16(1):8-14. Equivalence of bioimpedance and thermodilution in measuring cardiac index after cardiac surgery. Sageman WS, Riffenburgh RH, Spiess BD Pulmonary Medicine, Monterey, CA , USA

References continued

Equivalence of Bioimpedance and Thermodilution in Measuring Cardiac Output and Index in Patients with Advanced, Decompensated Chronic Heart Failure Hospitalized in Critical Care*Am J Crit Care*. 2004;13(6):469-479.Authors:Albert N, Hail M, Li J, Young JB.

Impedance Cardiography: The Next Vital Sign Technology?*Chest*. 2003;123(6):2028-2033.Authors:Van De Water JM, Miller TW.

Comparison of Impedance Cardiography to Direct Fick and Thermodilution Cardiac Output Determination in Pulmonary Arterial Hypertension. C*ongest Heart Fail*. 2004;10(2 suppl 2):7-10.Authors:Yung GL, Fedullo PF, Kinninger K, Johnson W, Channick RN.

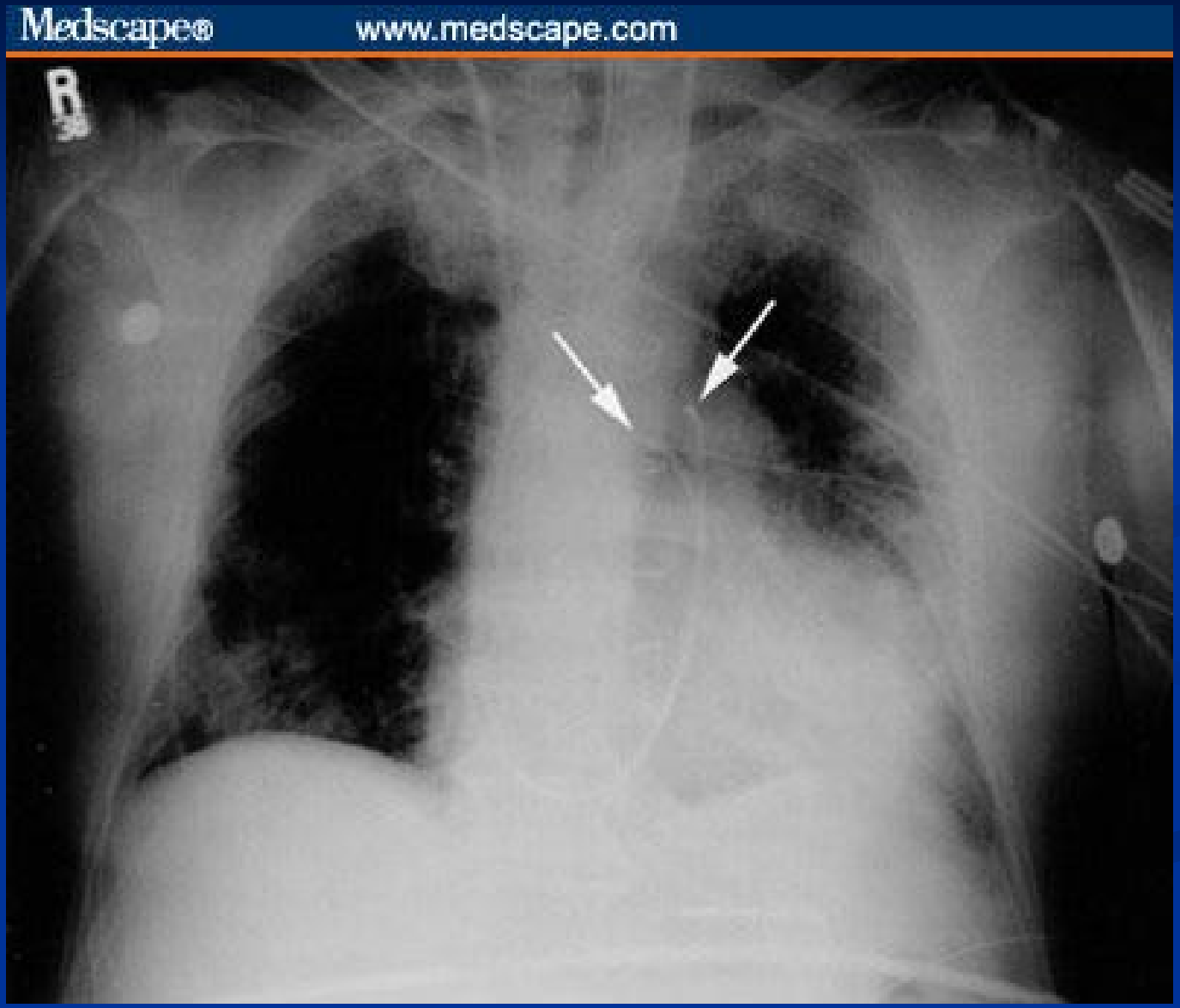
Congest Heart Fail. 2004 Mar-Apr;10(2 Suppl 2):17-21 Evaluation of impedance cardiography as an alternative to pulmonary artery catheterization in critically ill patients. Silver MA, Cianci P, Brennan S, Longeran-Thomas H, Ahmad F.

Can J Anaesth. 2005 May;52(5):530-4 Cardiac output by PulseCO is not interchangeable with thermodilution in patients undergoing OPCAB. Yamashita K, Nishiyama T, Yokoyama T, Abe H, Manabe M.

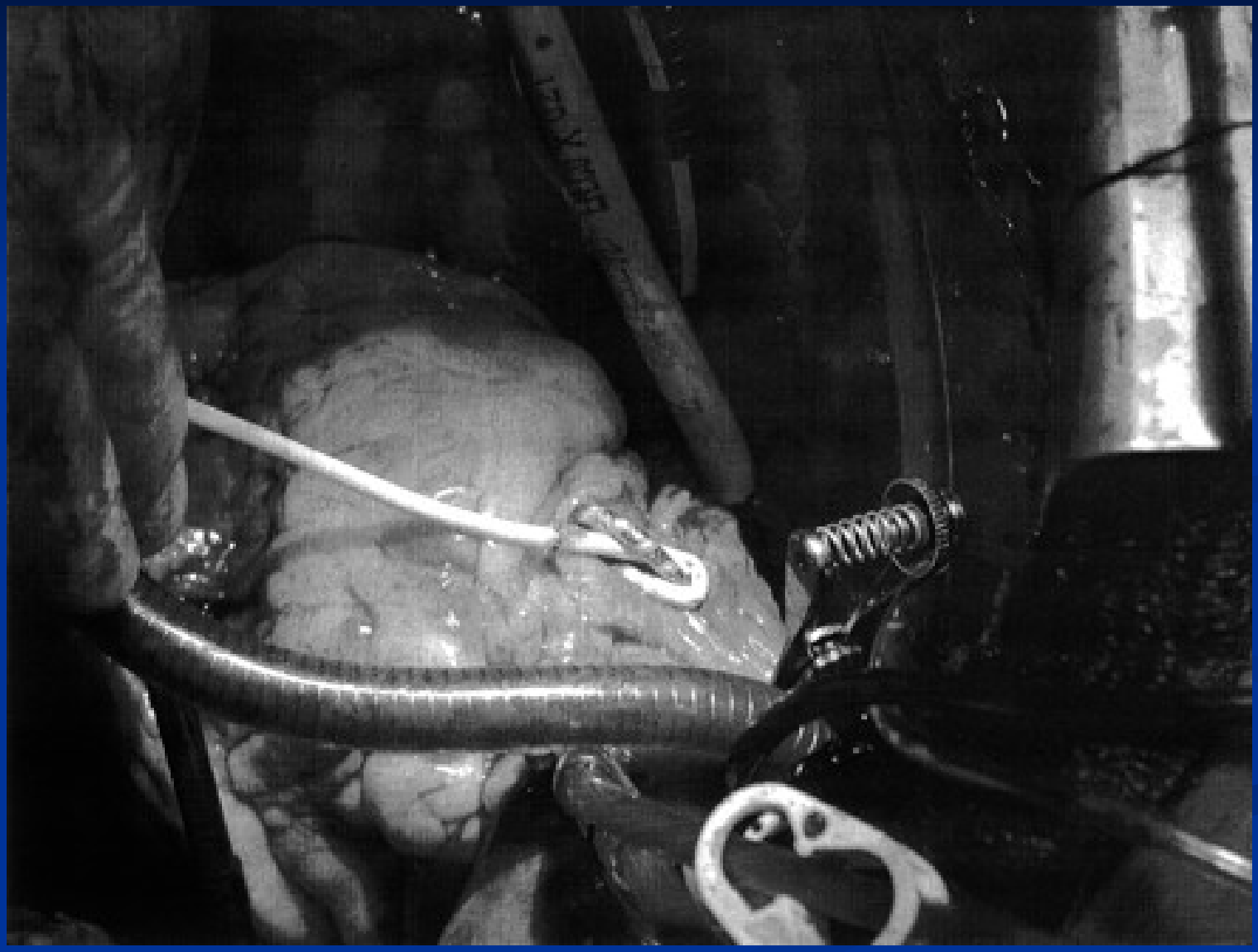
J Cardiothorac Vasc Anesth. 2000 Apr;14(2):125-9 Beat-to-beat measurement of cardiac output by intravascular pulse contour analysis: a prospective criterion standard study in patients after cardiac surgery. Zollner C, Haller M, Weis M, Morstedt K, Lamm P, Kilger E, Goetz AE.

Validation of Continuous Cardiac Output Measurement Using Arterial Pressure Waveforms William T. McGee et al Critical Care Supplement Mar 05

Two headed catheter



Nice PAC ……."KNOT"



Balloon leak